V. YELLOWSTONE NATIONAL PARK

A. GENERAL DESCRIPTION

Yellowstone National Park (YELL) was established as the world's first national park in 1872. YELL, comprised of 1.1 million ha, is at the center of approximately 6 million hectares commonly referred to as the Greater Yellowstone Ecosystem. These lands are managed by the National Park Service, USDA Forest Service, U.S. Fish and Wildlife Service, Bureau of Reclamation, Bureau of Land Management, three states (Wyoming, Montana, and Idaho), and many private landholders. Efforts are underway to manage the natural resources of this region at large spatial scales, with coordination among agencies and stakeholders, sharing of data and information, and cooperative management activities. Within YELL, natural resource management focuses on preserving the components and processes of naturally evolving ecosystems (YELL 1995). YELL ranges in elevation from 1,600 to 3,500 m, and contains several broad volcanic plateaus, and parts of three mountain ranges: the Absaroka Mountains in the eastern, Gallatin Mountains in the northwestern, and Red Mountains in the southern portions of the park.

The spectacular geological features of YELL, geysers, hot springs, mud pots, and fumaroles, provided the initial motivation for creation of the park. Forested ecosystems dominated by lodgepole pine (*Pinus cortorta*) occupy about 80% of the park, with various other grassland, alpine, and riparian vegetation interspersed with forest. This mosaic of ecosystems provides habitat for a wide range of megafauna including bison (*Bison bison*), elk (*Cervus elaphus*), moose (*Alces alces*), grizzly bear (*Ursus arctos* subsp. *horribilis*), black bear (*U. americanus*), mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), bighorn sheep (*Ovis canadensis*), pronghorn (*Antilocapra americana*), mountain lion (*Felis concolor*), and gray wolf (*Canis lupus*). Wildlife are found in densities rarely observed in other areas of North America. YELL's high quality aquatic habitats, including Yellowstone Lake and many trout-bearing streams, are also important features of the park's natural resources. Finally, the extensive backcountry of the park provides opportunities for hiking and solitude in a wilderness setting. A special feature of the current YELL landscape is the extensive area (400,000 hectares) that was burned in fires that occurred in 1988. The effects of this extreme fire event are a prominent ecological and visual component of park ecosystems and offer unique opportunities for observing and interpreting post-fire biological phenomena.

1. Soils and Geology

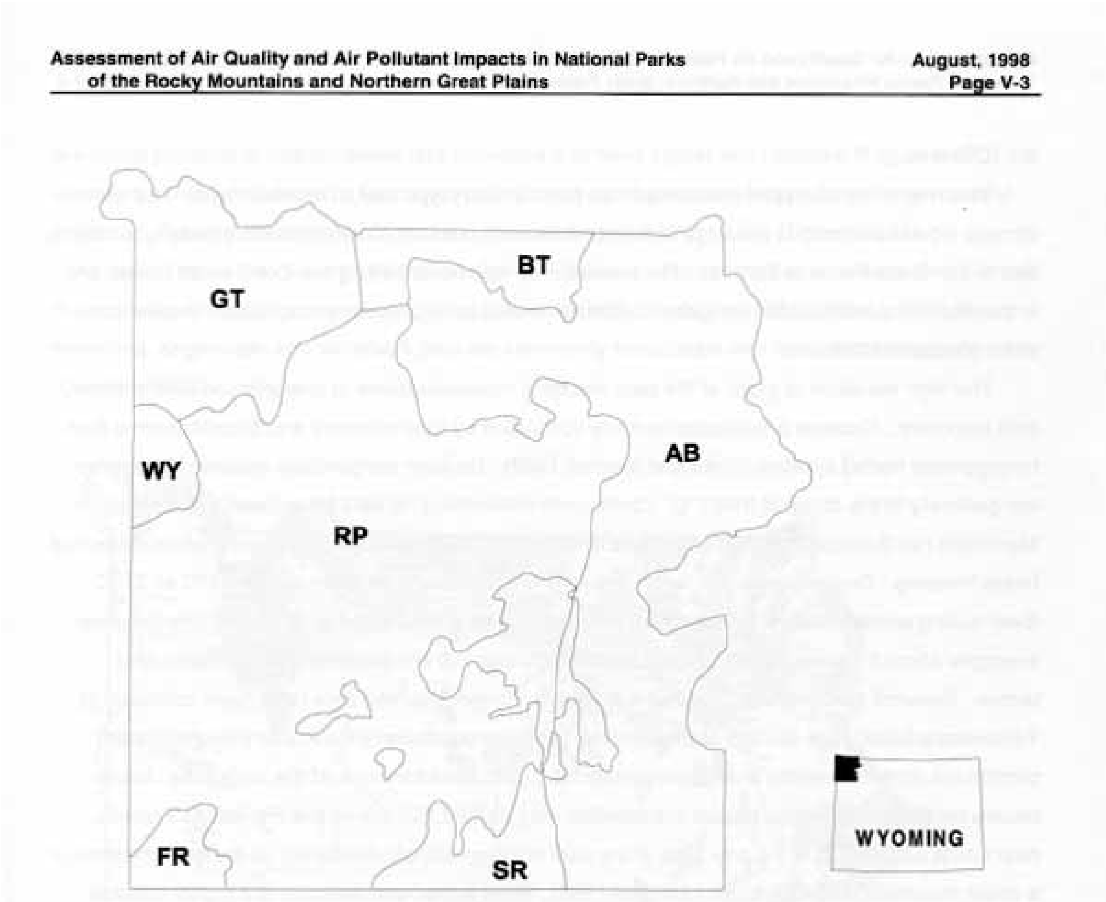
YELL is situated in an area comprised primarily of uplifted mountains of sedimentary rocks and the aftermath of two volcanic events (Romme 1982, Fournier et al. 1989). During the Eocene, volcanic activity created mountains in the north and along the eastern border of the current park. The volcanism formed mostly andesitic rocks that weather to soils relatively high in nutrients. During Quaternary times, a large caldera exploded in the central part of the park, leaving behind the lower one-third of a huge volcanic mountain (Mt. Washburn). The ash flows and later lava flows were rhyolitic in composition and are nutrient-poor. They produced the high plateau of the southwestern and central portions of the park (Figure V-1) (Despain 1990).

Soils derived from rhyolitic materials generally are more sensitive to acidic deposition because base cation concentrations tend to be lower. For example, calcium is much more abundant in andesite than in rhyolite. This, together with the higher clay content, provides for higher cation exchange capacity in the andesitic soils (Despain 1990).

Rock materials were transported from their places of origin by the glaciers that carved much of the Yellowstone area during the various periods of glaciation. The valleys of the Lamar River and the lower Yellowstone River were filled by a large glacier that transported parent material long distances and left behind deep layers of till. Elsewhere in the park, areas were generally covered by ice caps rather than large glaciers and the tills were not transported very far (Despain 1990).

The Yellowstone Plateau has an average elevation of about 2,500 m. The highest elevation in YELL is 3,500 m at Eagle Peak near the southeast corner of the park. The lowest point in the park (1,600 m) is in the northwest corner near Gardiner, Montana. The park straddles the point of contact of three major physiographic provinces (Clements 1910). These include the Middle Rocky Mountain Province which includes most of the park, the Northern Rocky Mountain Province, and the

Basin and Range Province. The Middle Rocky Mountain Province is characterized by mountains of



uplifted blocks with large intervening basins. Granitic rocks occur at the higher elevations and sedimentary rocks on the flanks of the mountains. The northern Rocky Mountain Province is characterized by high steep mountains and narrow basins of sedimentary rocks. It extends into the northern section of the park. Bordering the park on the west is the Basin and Range Province, which includes numerous mountain blocks and intermountain basins. Most of these mountains were formed along tension faults (Despain 1990).

The geyser basins of YELL are probably the best examples in the world of high-temperature geothermal activity. Boiling hot springs and geysers discharge significant quantities of circumneutral to slightly alkaline water. Such hydrothermal activity is most pronounced at the intersection of faults, especially within and around the Yellowstone Caldera. The waters are mostly chloride-rich and deposit siliceous sinter that accumulates into thick mounds and terraces. Acid-sulfate boiling pools and mud pots also occur in some of the geyser basins. Thermal waters at Mammoth are somewhat different. They flow to the surface through a thick sequence of sedimentary rocks that includes limestone, dolomite, and gypsum-bearing shales, and are therefore rich in sulfate and bicarbonate (Fournier 1989).

AB Absaroka region is predominantly andesitic lava flows and breccia, with basalt, and some occurrence of rhyolite, sandstone, and limestone

BT Beartooth region is a mix of Precambrian granites, Paleozoic and Mesozoic sandstones and shales, and Tertiary/Quaternary volanics

FR Falls River region is Quaternary rhyolite and basalt, frequently overlain by alluvial and glacial deposits

GT Gallatin region is Precambrian granites, Paleozoic and Mesozoic limestones, sandstones, and shales, Tertiary/Quaternary volcanics

RP Rhyolite plateau region is predominantly Tertiary and Quaternary rhyolite flows

SR Snake River region is Paleozoic and Mesozoic limestones, sandstones, and shales, with some outcroppings of Tertiary rhyolite and andesite

WY West Yellowstone region is rhyolite overlain by alluvial, glacial, and lacustrine deposits

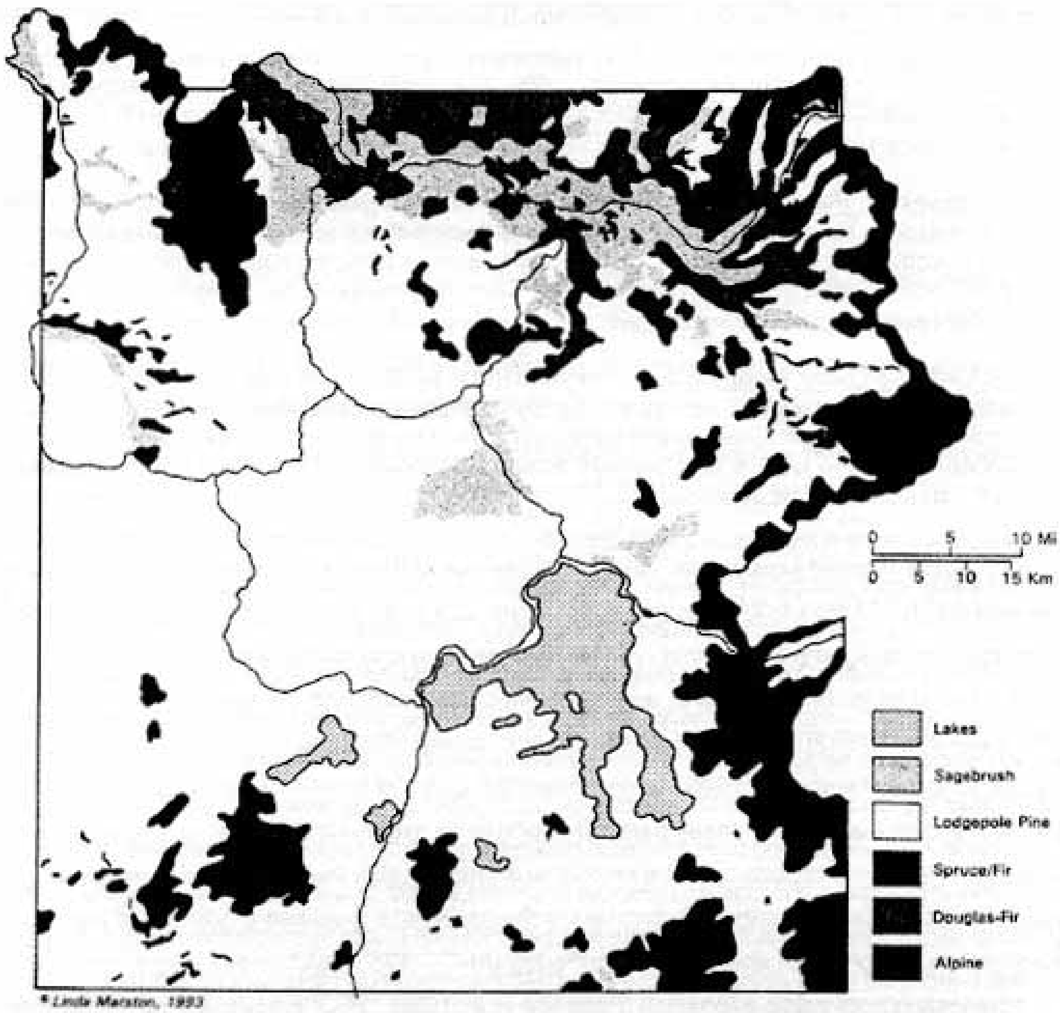


Figure V-2. Major vegetation types, roads, and large lakes in YELL. Based on classifications from a map prepared by Despain (1990).

Figure V-1. Regional-geological map of YELL (adapted from Cox 1973 by Gibson et al. 1983).

2. Climate

Two major climatic types are found in the park: a valley type and a mountain type. The valley climatic type is common to the large valleys and central plateaus. This climate is generally similar to that of the Great Plains to the east. The mountain climate occurs along the Continental Divide and in the Absaroka and Gallatin Ranges. It is characterized by high winter precipitation, mostly as snow (Despain 1990).

The high elevation of much of the park results in moderate levels of precipitation and relatively cool summers. Summer precipitation is more dominated by local showers and thunderstorms than by organized frontal systems (Dirks and Martner 1982). Daytime temperature maxima in summer are generally in the range of 21-27°C. Continuous meteorological data have been collected at Mammoth Hot Springs since 1887. Winters are cold with daily temperature maxima often remaining below freezing. Temperatures can reach extreme values in the park, from about -54°C to 37°C. Even during summer, below freezing temperatures can be encountered at any time. Precipitation averages about 64 cm annually, ranging between 30 and 100 cm depending on elevation and terrain. Snowfall reaches 5 to 10 m in the Absaroka Range. Rainfall data have been collected at Yellowstone Lake since the turn of the century. Winter precipitation (November through March) contributes most to the total annual precipitation and accounts for much of the variability. Snow course records suggest that annual precipitation may exceed 200 cm on the Pitchstone Plateau near Lewis Lake. This is the only area of the park not immediately downwind (in the rain shadow) of a major mountain range (Dirks and Martner 1982). Wind speed and direction are highly variable within the park, and are strongly dependent on local topography and elevation. Prevailing winds are from the southwest at the meteorological tower location.

3. Biota

The flora of YELL includes over 1,200 vascular plant species, including about 150 non-native species, and over 180 species of lichens (Eversman 1990). Most of these plants are documented in the park's herbarium. Vegetation and habitat maps and descriptions have been compiled for the park at a 1:125,000 scale. The vegetation has been altered drastically, at least with respect to age class and to some extent cover type, due to the extensive fires of 1988. Burned area and burn intensity maps have been produced at large scale and at 1:20,000.

Approximately 80% of the land area of YELL is forested. Lodgepole pine and some limber pine (*Pinus flexilis*) occupy about 700,000 ha of the total area of the park. Subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) are found at higher elevations and higher soil moisture sites at lower elevations; Douglas-fir (*Pseudotsuga menziesii*) is found at low elevations in the northern part of the park; whitebark pine (*Pinus monticola*) is found at higher elevations; and a small amount of aspen (*Populus tremuloides*) and cottonwood (*Populus *balsamifera* subsp. *trichocarpa*) are found primarily in riparian areas and drainages that have higher soil moisture (Figure V-2). Low-elevation nonforested areas of the park are dominated by sagebrush (*Artemisia* spp.) and several grass species such as wild rye (*Elymus* sp.) and needlegrass (*Stipa* sp.). High-elevation nonforested areas are dominated by distinctive low-stature plants adapted to an alpine environment. Subalpine fir and lodgepole pine tend to be associated with rhyolitic parent materials, while mesic meadows, sagebrush, and whitebark pine are commonly associated with andesitic parent materials (Despain 1990).

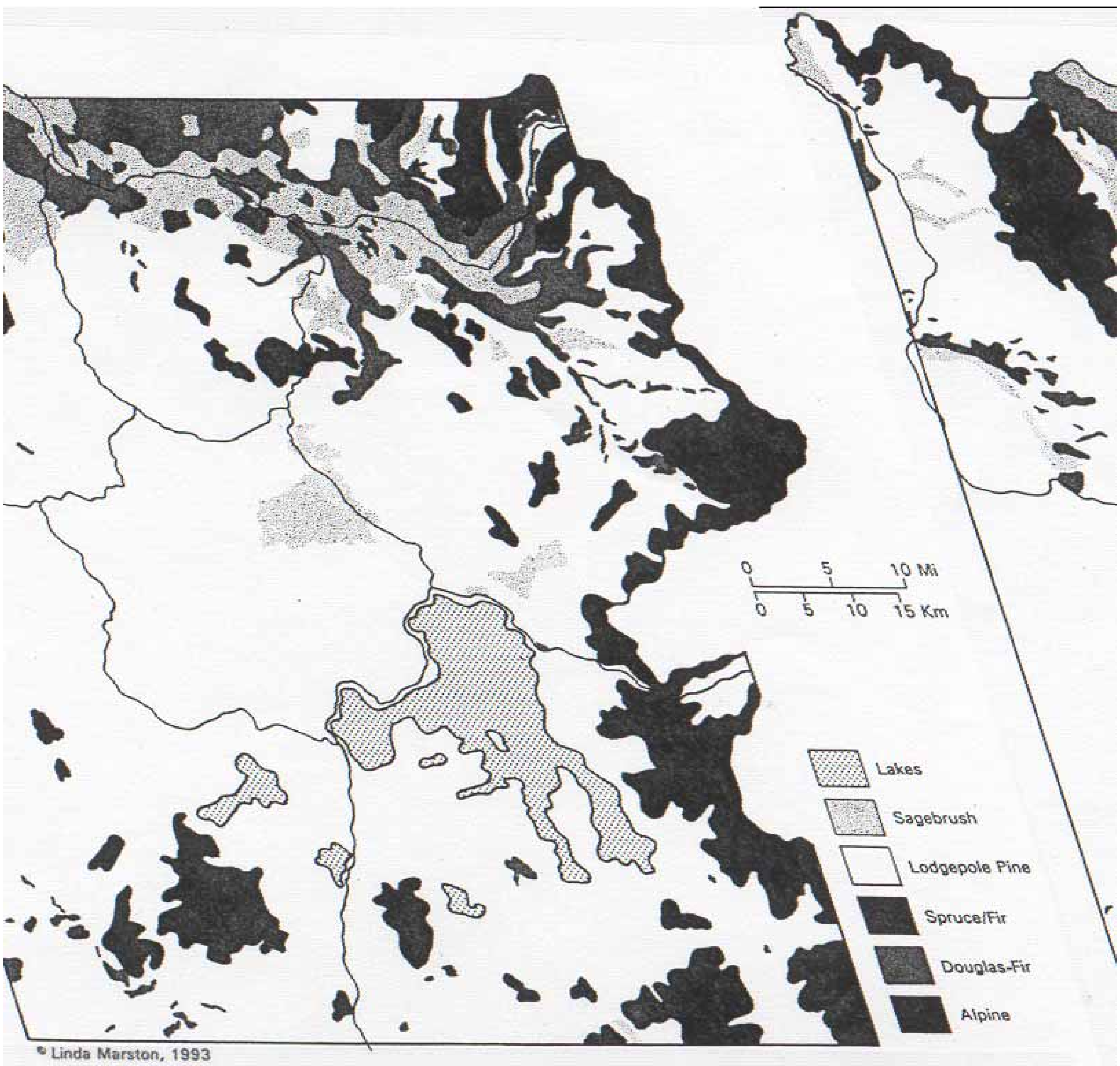


Figure V-2. Major vegetation types, roads, and large lakes in YELL. Based on classifications from a map prepared by Despain (1990).

Despain (1990) described five "geovegetation provinces" in the park:

- Gallatin Range -- Located in the northwest, this province occupies 7% of the park. It contains andesitic and sedimentary rocks, which weather to soils with high clay content. The province is 75% forested, with the dominant species subalpine fir, whitebark pine, Engelmann spruce, and Douglas-fir. Idaho fescue (*Festuca idahoensis*)and bearded wheatgrass (*Elymus trachycaulus*) dominate meadow vegetation.

- Absaroka Range -- Located along the eastern edge and southeast, this province occupies 32% of the park. Absaroka volcanics predominate. The province is 77% forested, with the dominant species lodgepole pine, whitebark pine, subalpine fir, and Engelmann spruce. Idaho fescue and bearded wheatgrass dominate meadow vegetation.

- Central Plateaus -- Located mostly in the central region, this province occupies 34% of the park and is underlain by Quaternary rhyolite. The mostly flat and undulating plateaus are 90% forested, with the dominant species lodgepole pine, with some subalpine fir and Engelmann spruce.

- Southwestern Plateaus -- Located in the southwest, this province occupies 18% of the park. This province is underlain by relatively recent rhyolitic flows with additional basalt flows. The flat to undulating plateaus are dominated by lodgepole pine, subalpine fir, and whitebark pine. Nonforested types are dominated by Idaho fescue and tufted hairgrass (*Deschampsia caespitosa*).

- Yellowstone-Lamar River Valleys -- Located in the north-central area, this province occupies 9% of the park area. The valleys are mostly filled with glacial drift comprised of andesitic and sedimentary materials. Nonforested vegetation dominates this province, with big sagebrush, Idaho fescue, and bearded wheatgrass the most common species. Douglas-fir is the dominant forest species.

The diversity of wildlife species in YELL is well-known to the scientific community as well as to the general public. There are 44 mammal species and 279 bird species recorded in YELL. Several of these species have been the subject of extensive research and monitoring. There are six species of reptiles, four species of amphibians, and 13 native species of fish in the park.

Peterson et al. (1992) sampled eight sites in and around YELL and GRTE on several occasions during the spring and summer of 1991 to determine the status of amphibian populations. The amphibian species that occur in these parks are apparently experiencing problems elsewhere within their ranges. Data were collected on the amphibians present, plus the physical and biological conditions at each site, including elevation, water chemistry, and presence of fish. All of the sampled ponds had pH $\geq$ 6.8 and sufficient buffering (ANC $\geq$ 175 µeq/L) so that they were not at risk of acidification from acidic deposition (Peterson et al. 1992). Four species of amphibians were found: western toad (*Bufo boreas*), spotted frog (*Rana pretiosa*), western chorus frog (*Pseudacris triseriata*), and tiger salamander (*Ambystoma tigrinum*).

4. Aquatic Resources

YELL encompasses near-pristine watershed areas and contributes to two of the nation's farthest reaching drainages: the Missouri and Columbia Rivers. Surface water resources in the park include about 600 streams and 175 lakes. There are about 4,400 km of free-flowing rivers and streams. Four large lakes (Yellowstone, Shoshone, Lewis, and Heart Lakes) account for about 94% of the park's lake surface. The largest lake in the park is Yellowstone Lake, which is 92 m deep and 386 km^2 in area. Major rivers include the Yellowstone, Snake, Lewis, Madison, Gibbon, Firehole, Gardiner, and Lamar Rivers. Water quality varies throughout the park, mostly as a function of geologic terrain and the influence of thermal features. Natural geothermal discharges, which are quite common in many portions of the park, affect the pH, alkalinity, temperature, salinity, sulfate concentrations, and base cation concentrations of drainage waters. Snowmelt is an important contributor to hydrologic budgets of watersheds in the park, and water quality therefore tends to vary seasonally.

Yellowstone Lake is noteworthy in a number of respects. The largest high-altitude lake in North America, it lies mostly within the Yellowstone Caldera, which has some of the highest measured geothermal heat fluxes in the world (Klump et al. 1988). Hydrothermal springs and hot gas fumeroles occur within the lake. Enhanced biological activity occurs around the geothermal vents which are characterized by high temperature, anoxia, and high concentrations of dissolved nutrients. Microbial communities are dense, as are the populations of oligochaete worms near fumeroles in the warm sediments.

Two subspecies of cutthroat trout (*Oncorhynchus clarki*) are native to the park: the Yellowstone cutthroat (*O. c. bouvieri*) and the west slope cutthroat (*O. c. lewisi*). In addition, non-native fish, including lake trout (*Salvelinus namaycush*), have been introduced. Fishing management is attempting to manage aquatic resources as functional components of the Greater Yellowstone Ecosystem and to preserve and restore native species and aquatic habitats.

The Yellowstone cutthroat was originally widely distributed in the intermountain region (Varley 1979), although its range is now greatly reduced. Four recognized strains occur in the park. The Yellowstone Lake strain, at one time the largest inland cutthroat trout population in the world, declined markedly in the 1950's and 1960's (Jones et al. 1986). A series of restrictive fishing regulations have been implemented. The McBride Lake strain is able to efficiently utilize available food resources in marginal oligotrophic environments. The Sedge Creek strain developed after Sedge Creek and Bear Creek were effectively isolated from Yellowstone Lake by Turbid Lake, a geothermal body of water, when the lake stage of Yellowstone Lake decreased. The toxicity of Turbid Lake prevents fish from migrating downstream. The Heart Lake cutthroat is the only piscivorus strain of Yellowstone cutthroat trout. The status of the West Slope cutthroat in the Upper

Missouri River has been greatly altered by the introduction of other salmonids. No verified pure populations of west slope cutthroat trout are known to exist in the park (Mary Hektner, YELL, pers. comm.).

B. EMISSIONS

YELL is located in the northwestern corner of Wyoming surrounded by Bridger-Teton, Shoshone, and Targhee National Forests and lies 10 km north of Grand Teton National Park. There is little industrial activity and low population in this portion of the state, resulting in good air quality. Most of the industrial activity in Wyoming is in the eastern counties near the cities of Gillette and Casper, and in the southwestern counties around Rock Springs. Oil and gas processing, electric utility power plants and industrial fossil-fuel combustion in southwestern Wyoming and southeastern Idaho are the major sources of gaseous pollutants in the YELL area. Annual emissions of gaseous SO_2, NO_x and VOC are primarily from fossil-fuel combustion by industrial sources (Tables II-2, II-3 and II-4), and levels are moderate relative to other western states.

Point sources of SO_2 , NO_x, and VOC located within 150 km of YELL (with emissions exceeding 100 tons/yr) are listed in Table V-1. Adjacent counties in Idaho and Montana are included. In Wyoming, SO_2 emissions are mainly from oil and gas refineries, the largest of which is Amoco Production Co. (emitting over 1,200 tons/yr) located in Elk Basin, 100 km east of YELL. The largest regional sources of SO_2 within 150 km of YELL are the Monsanto Company and Nu-West Industries, both mining operations located approximately 100 km south of YELL in Caribou County, southeastern Idaho. The annual emissions from these companies (approximately 9,000 tons/yr combined) may have an impact on resources in YELL.

Sources of NO_x in Wyoming are electric utilities and industrial fossil-fuel combustion (Table II-3). Current point sources of NO_x within 150 km of YELL are listed in Table V-1. The largest regional source of NO_x is Monsanto Corporation located in Caribou County, southeastern Idaho. Major stationary sources of VOC emissions, an important ozone precursor, are relatively low in Wyoming. However, there are thousands of small VOC and NO_x sources that cumulatively may add up to much higher emission totals (T. Blett, pers. comm.).

Seasonal increases in carbon monoxide (CO) are a concern in areas of high snowmachine use within YELL. Since the mid 1970's, snowmachine use has been an increasingly popular winter tourist activity. During the winter of 1993-94, over 87,000 tourists visited Old Faithful by snowmachine (Fussell 1997). Emissions from snowmachines are not regulated, and the vehicles are not required to utilize emission control equipment. Consequently, emissions of CO and unburned hydrocarbons from snowmachines can exceed those of automobiles (L.M. Snook pers. comm.). During winter 1994-95, one-hour samples taken near the west entrance station of YELL exceeded 35 ppm at two sites, and the 8-hour average CO concentration exceeded 8 ppm at one

Table V-1. Point sources (tons/yr) of SO_2, NO_x, and VOC (annual emissions exceeding 100 tons/yr of at least one pollutant) within 150 km of YELL. (Source: Idaho Department of Health and Welfare, unpublished data; Martin 1996; Wyoming Department of Environmental Quality 1995)

	SO_2	NO_x	VOC
Wyoming			
Amoco Co.	1,218	603	208
Marathon Oil	21	7	869
Oregon Basin Gas	455	25	49
Questar Pipeline		100	10
Williams Field Services (3 sites)		1,381	740
Williston Basin IPC		162	69
Idaho			
Ash Grove Cement	889	802	31
Basic American Foods	498	174	4
Basic American Foods	193	37	54
Chevron Pipeline			437
Idaho National Engineering Labs	91	1,229	35
Idaho Pacific Corp.	131	156	1
Idaho Supreme Potatoes	136	151	1
J.R. Simplot - siding facility	2,554	646	131
Monsanto Co.	4,703	2,021	
Nu-West Industries, Inc.	4,369		
Pillsbury Co.	1	156	7
Montana			
Cenex	2,865	892	892
Conoco	959	700	990
Exxon Co.	8,738	736	1,082
Holnam Inc.	32	1,330	2
Luzenac America	25	242	25
Montana Power Co.		100	25
Montana Power Co.	6,439	3,467	24
Montana Sulfur	3,422	11	
Western Sugar	486	360	17

site (NPS 1995). The health of park staff at entrance kiosks and of snowmachine users in groups may be at risk.

C. MONITORING AND RESEARCH ACTIVITIES

1. Air Quality

a. Wet Deposition

Precipitation volume and chemistry have been monitored at Tower Junction since 1980 by NADP/NTN (Figure V-3). Annual precipitation amounts are generally in the range of 30 to 45 cm per year at this site. The concentration of SO_4^{2-}, NO_3^-, and NH_4^+ are low, with each generally below 10 μeq/L (Table V-2). The combined low amount of precipitation and low concentrations of

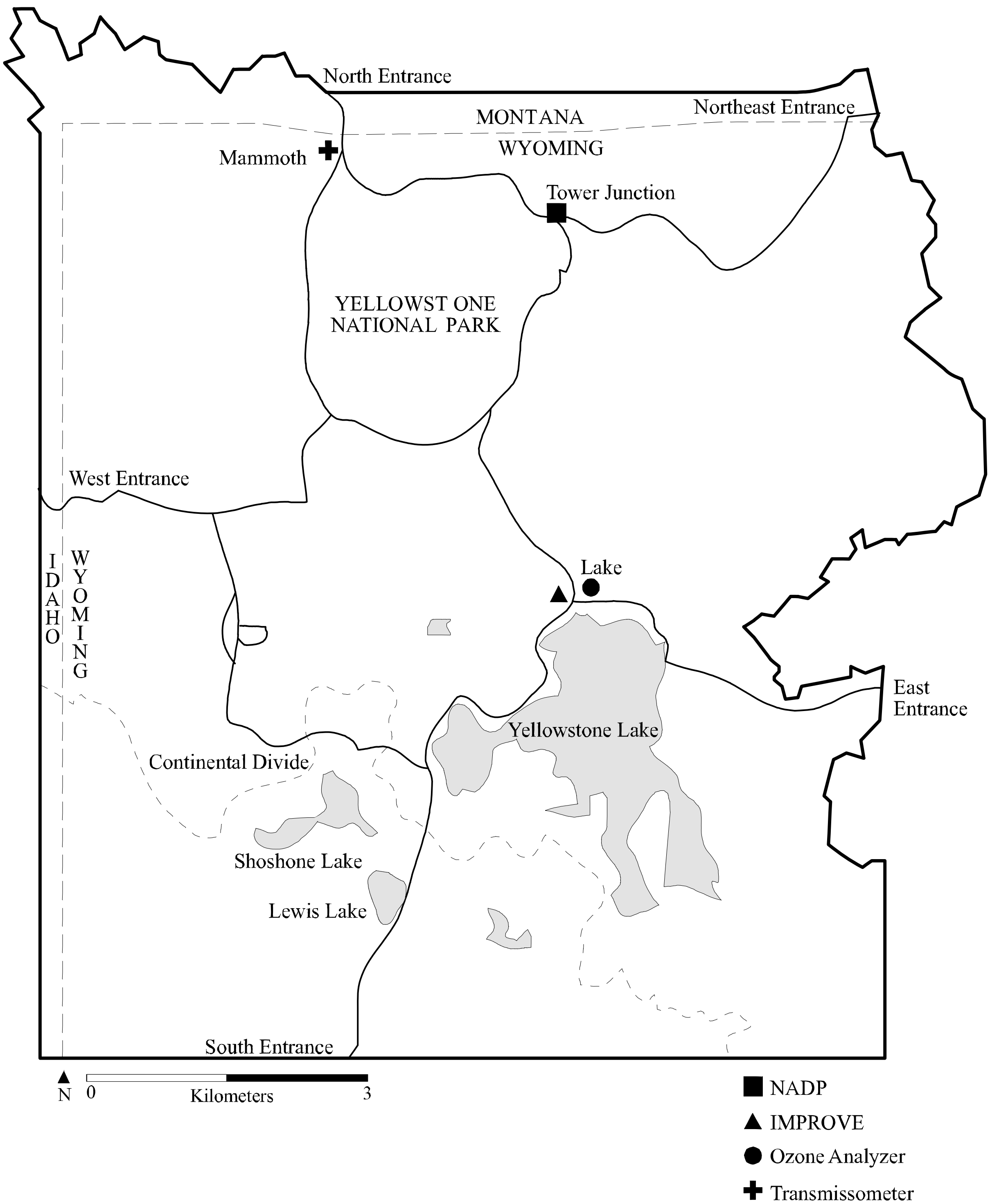


Figure V-3. Air quality monitoring locations at YELL. NOTE: ozone analyzer was moved in 1995.

Table V-2. Wetfall chemistry at the NADP/NTN site at Tower Junction, YELL. Units are in μeq/L, except precipitation (cm).

Year	Precip	H^+	SO_4^{2-}	NH_4^+	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-
1995	38.7	5.3	5.8	7.7	7.7	4.8	0.9	1.8	0.5	1.8
1994	36.3	4.6	9.7	9.8	10.3	12.5	2.3	3.1	0.9	2.5
1993	39.6	2.6	8.6	8.3	8.1	6.6	1.4	2.6	0.4	2.1
1992	45.0	2.7	8.1	8.3	8.5	12.1	2.0	2.0	0.6	2.4
1991	45.5	2.6	11.0	6.8	9.7	14.8	2.7	4.1	0.6	2.5
1990	36.6	3.4	12.0	9.4	11.6	18.4	3.2	3.5	1.2	3.8
1989	42.9	2.1	8.7	8.8	9.4	12.2	2.3	3.0	0.6	3.3
1988	27.3	1.9	7.1	3.5	4.6	9.9	1.7	3.6	0.7	2.6
1987	8.7	2.6	4.5	3.2	4.6	5.7	1.1	2.5	0.3	1.9
1986	38.8	2.8	8.1	5.7	6.7	9.0	1.9	2.5	0.7	2.7
1985	36.1	3.0	6.6	2.9	5.4	6.4	2.0	2.0	0.6	2.5
1984	37.5	5.6	12.2	7.2	9.0	14.4	3.9	4.0	1.4	4.0
1983	34.5	3.6	11.0	5.0	5.8	10.9	2.8	3.8	1.1	3.2
1982	57.1	6.0	12.7	5.0	7.5	11.8	4.1	4.1	1.2	4.0
1981	34.1	4.4	32.6	9.6	11.7	21.9	8.2	26.1	1.6	13.4
1980	24.7	7.4	22.2	11.7	14.6	14.4	3.1	6.8	1.3	5.9

acid-forming precursors results in very low levels of sulfur and nitrogen deposition. Sulfur deposition is generally well below 1 kg S/ha/yr and N deposition is seldom above this amount (Table V-3).

Snowpack samples were collected in March or April of 1993 through 1998 at five sites in YELL: West Yellowstone, Lewis Lake Divide, Sylvan Lake, Canyon, and Twenty-one Mile. Sulfate concentrations in snow were low at all sites, with five-year (1993-1997) mean concentrations ranging from 4.7 μeq/L at Sylvan lake to 8.0 μeq/L at West Yellowstone. Mean concentrations of NO_3^- in the snowpack ranged from 4.2 μeq/L at Canyon to 5.0 μeq/L at Lewis Lake Divide. Ammonium concentrations were similar to NO_3^- concentrations, with mean values ranging from 4.2 μeq/L at Canyon to 7.0 μeq/L at West Yellowstone (G.P. Ingersoll, pers. comm.). Although higher than comparable measurements made in GLAC, these snowpack ionic concentrations were similar to those in GRTE and are considered low.

b. Occult/Dry Deposition

There are no data currently available on dry or occult deposition fluxes of S or N to sensitive resources within YELL. However, we expect that the contributions of both dry and occult deposition of S and N are low relative to the wet deposition amounts summarized in Table V-3. This is

Table V-3. Wet deposition (kg/ha/yr) of sulfur and nitrogen at the NADP/NTN site at Tower Junction, YELL.

Year	Sulfur	NO_3-N	NH_4-N	Total Inorganic N
1995	0.4	0.4	0.4	0.8
1994	0.6	0.5	0.5	1.0
1993	0.5	0.4	0.5	0.9
1992	0.6	0.5	0.5	1.1
1991	0.8	0.6	0.4	1.1
1990	0.7	0.6	0.5	1.1
1989	0.6	0.6	0.5	1.1
1988	0.3	0.2	0.1	0.3
1987	0.1	0.1	0.0	0.1
1986	0.5	0.4	0.3	0.7
1985	0.4	0.3	0.1	0.4
1984	0.7	0.5	0.4	0.9
1983	0.6	0.3	0.2	0.5
1982	1.2	0.6	0.4	1.0
1981	1.8	0.6	0.5	1.0
1980	0.9	0.5	0.4	0.9

because there are no significant emission sources in close proximity to the park and because the amounts of wet deposition are low. Atmospheric concentrations of S and N species have been measured in YELL since 1996 as part of the National Dry Deposition Network (NDDN). Dry deposition flux calculations are not yet available, but are expected to be available in the near future.

c. Gaseous Monitoring

Ozone is not currently monitored by the state, and at present the only continuous ozone analyzer in Wyoming is operated and maintained by the NPS in YELL. Maximum hourly ozone concentrations at Tower Junction between 1987 and 1994 ranged between 61 and 98 ppbv (Table

V-4). These levels are below the NAAQS for ozone. The mean daytime 7-hour ozone concentration during the growing season ranged between 41 and 45 ppbv during this time period. The SUM60 exposure index is another indicator that can be important in assessing ozone exposures of plant species. This index is the sum of all hourly ozone concentrations equaling or exceeding 60 ppbv. The SUM60 exposure index at YELL ranged between 363 and 11,376 in this time period. For comparison, national parks in highly polluted areas (e.g., southern California) can have SUM60 exposure indexes exceeding 100,000 ppbv-hour (Joseph and Flores 1993). The continuous ozone analyzer at YELL was moved to the Lake area in 1995.

Table V-4. Summary of YELL ozone concentrations (ppbv) from NPS monitoring sites (Joseph and Flores 1993).

	1987[a]	1988	1989	1990	1991	1992	1993	1994[b]
1-hour maximum	88	98	71	61	64	75	62	72
Average daily mean	34	37	33	31	35	36	35	39
Growing season 7-hour mean	41	44	45	34	42	42	41	47
SUM60 exposure index (ppbv-hour)	2,378	11,376	6,658	483	1,169	6,315	363	6,015

[a] data collected from June through December
[b] NPS Monitoring data

Most of the monitoring data at YELL indicate that the park has excellent air quality. However, there are relatively few data from other agencies in the Greater Yellowstone Ecosystem area to support the limited database in the park. Concerns about visibility and the value of scenic vistas to the public were apparent during the large fires of 1988, which points out the social intolerance to degradation of the visual resource.

Sulfur dioxide has been measured in YELL since 1988, and annual average concentrations range from 0.02 to 0.08 ppbv (Table V-5). The highest 24-hour SO_2 concentration measured in the park was 0.73 ppbv. These values are much lower than the concentration that is considered potentially damaging to some vegetation (Treshow and Anderson 1989).

Levels of CO have been measured seasonally since 1992 in connection with increased snowmachine use in the Park. Because winter visitation of YELL is primarily via motorized snow vehicles and has increased nearly ten-fold during the past decade, the potential effects of vehicle emissions during winter have become an important concern for resource managers at YELL (Ingersoll et al. 1997). Air quality monitoring at the west entrance to the park during 1995 detected

Table V-5. Maximum and mean SO_2 24-hour integrated sample. The clean-air reference is estimated to be 0.19 ppbv (Urone 1976). (Source: J. Ray, NPS Air Resources Division)								
	SO_2 concentration (ppbv)							
	1989	1990	1991	1991	1992	1993	1994	1995
Maximum	0.18	0.30	0.73	0.20	0.20	0.03	0.14	0.07
Mean	0.02	0.05	0.08	0.03	0.05	0.04	0.04	0.02

CO levels exceeding Federal standards. At this entrance to the park, as many as 1,000 over-snow vehicles have entered on peak traffic days. Furthermore, analyses of snowpack chemistry within the YELL area during 1993-1995 suggested that the volume of snowmachine traffic might correlate with the concentration of NH_4^+, NO_3^-, or SO_4^{2-} in the snowpack. Therefore, Ingersoll et al. (1997) conducted a survey of snowpack chemistry at six sites within the park to determine if emissions from snowmachine traffic are detectable in the snowpack and also whether pollutant loads diminish rapidly with distance from the snowmachine thoroughfares. Three locations that represent variable levels of over-snow traffic were selected. At each of the three locations (West Yellowstone, Old Faithful, and Sylvan Lake) an off-road site was paired with a site in the snowmachine roadway (about 20 to 100 m apart), and snow core samples were collected and analyzed at each. Snowpack chemistry from the off-road and in-road sites at Sylvan Lake showed similar patterns (Table V-6), probably due to the low level of snowmachine traffic. However, the higher traffic sites showed greater deposition of all three ions. Also, comparisons of results for the in-road and off-road sites at West Yellowstone and Old Faithful showed concentrations of NH_4^+ and SO_4^{2-} (but not NO_3^-) higher in the snowpacked road, compared to the respective off-road site (Table V-6). Ingersoll et al. (1997) concluded that the source of NO_3^- was more likely regional, whereas the concentration of NH_4^+ and SO_4^{2-} seemed to be influenced by local air quality influences such as snowmachines. Although snowmachines may be causing increased local deposition of NH_4^+ and/or SO_4^{2-}, the concentrations in the snowpack are relatively low (< 10 μeq/L) and seem to decrease substantially at short distance from the roadways.

Table V-6. Snowmachine usage levels and chemical concentrations (μeq/L) at snow-sampling sites in YELL (data from Ingersoll et al. 1997).

Site Name	Level of Snowmachine Use	NH_4^+	NO_3^-	SO_4^{2-}
West Yellowstone (off-road)	high	5.1	7.9	4.2
West Yellowstone (in-road)	high	8.9	7.9	8.8
Old Faithful (off-road)	moderate-to-high	5.2	8.4	4.0
Old Faithful (in-road)	moderate-to-high	7.2	8.4	6.2
Sylvan Lake (off-road)	low	3.0	3.9	3.3
Sylvan Lake (in-road)	low	3.5	4.1	4.0

2. Water Quality

EPA's Storage and Retrieval (STORET) database contains about 29,000 observations from the Yellowstone area for 164 water quality parameters at 444 sites. Thirty-five sites within the park have long-term records consisting of multiple observations for several important water quality parameters. Water pH was measured 776 times at 228 sites from 1964 through 1992. Of those, only 44 measurements had pH less than 6.5, at about 20 sites. Total alkalinity by low-level Gran analysis was determined at eight sites, three of which had measured alkalinity less than 200 μeq/L (Grassy Lake Reservoir [0003], Fern Lake [0240], and No Name Lake [0127]). Fern Lake is known to have geothermal sources, based on sampling by the U.S. EPA's Western Lake Survey (WLS; Landers et al. 1987). Sulfate concentrations were measured 786 times at all sites from 1964 through 1992 and exceeded the drinking water criterion of 400 mg/L (8,300 μeq/L) at four sites near Mammoth Hot Springs.

The NPS maintains a database of water quality and flow data for YELL, based on retrievals from five of EPA's national databases, mostly from STORET. pH values are available in this database for one or more sampling occasions from 201 sites, 5 of which had pH < 5.5. However, none of the lakes or streams having pH < 5.5 exhibited other data that reflected sensitivity to acidification from acidic deposition (Table V-7). For example, sulfate concentrations ranged from 18 mg/L to 191 mg/L in the low-pH waters, more than an order of magnitude higher than would be attributable to atmospheric deposition due to air pollution. Chloride concentrations were also high in most of these surface waters, ranging from 1 mg/L to 121 mg/L. Four of the five lakes with pH < 5.5 had chloride concentration >57 mg/L. It is likely that all of these surface waters are impacted by geothermal discharge that cause the water to be low in pH.

The WLS sampled six lakes in YELL and nine lakes in surrounding areas (Landers et al. 1987; Table V-8). One of the lakes in the park was acidic (ANC = -24 μeq/L). This acidity was attributable to geothermal inputs as evidenced by the extremely high concentrations of SO_4^{2-} (818 μeq/L) and

Table V-7. Data on selected variables for the five lakes and streams in the YELL database that had measured pH less than 5.5.

Name	pH	Cl (μeq/L)	SO_4 (μeq/L)	Specific conductance (μS/cm)
YELL 0136	3.4	3,413	1,562	702
YELL 0192	4.3	2,003	3,979	692
Harlequin Lake	5.4	28	375	70
Beaver Lake	5.1	2,482	2,292	71
Nymph Lake	5.0	1,608	3,125	725

Table V-8. Results of lakewater chemistry analyses by the Western Lake Survey for selected variables in YELL and adjacent areas.										
Lake ID	Lake area (ha)	Watershed area (ha)	Elevation (m)	pH	ANC μeq/L	SO_4^{2-} μeq/L	NO_3^- μeq/L	Ca^{2+} μeq/L	C_B μeq/L	DOC mg/L
Lakes Within YELL										
4D3-013	11.3	75	2006	9.4	1510	17	0.4	1092	1618	5.5
4D3-016	4.6	523	2287	5.7	1332	2909	3.5	599	6682	3.5
4D3-017	38.8	297	2514	4.8	-24	818	0.3	243	1330	6.2
4D3-019	20.8	168	2392	6.6	139	6	0.0	112	220	11.2
4D3-052	15.5	367	2198	8.3	705	30	0.3	311	980	4.8
4D3-073	3.4	119	2677	8.5	416	8	0.0	356	429	1.9
Lakes Outside YELL										
4D2-050	1.5	64	2920	7.0	59	8	0.3	35	75	1.6
4D2-003	4.2	49	2793	7.5	161	7	0.7	66	184	1.3
4D3-001	76.2	7127	2037	8.6	630	33	0.4	436	737	1.2
4D3-002	3.2	80	2915	6.8	57	28	5.0	54	88	0.6
4D3-004	4.9	38	2935	7.1	79	9	0.5	45	101.	1.5
4D3-006	3.0	75	2904	7.7	250	31	0.4	142	278	0.7
4D3-056	3.5	178	2935	6.9	45	11	0.3	32	66	1.8
4D3-028	2.1	31	2482	9.4	3795	109	1.6	1335	4284	16.7
4D3-024	20.7	481	3028	7.5	214	9	0.2	136.	236	0.7

sum of base cations (C_B, 1,330 μeq/L). One lake had an ANC of 139 μeq/L; its pH was also relatively low (6.6), mainly as a consequence of the high concentration of dissolved organic carbon (11 mg/L). Several of the lakes in surrounding areas surveyed by the WLS were more acid-sensitive than those in the park; four of nine had ANC less than 100 μeq/L and one was below 50 μeq/L. Most of these had low SO_4^{2-} concentrations that could reasonably be attributed to atmospheric inputs (~ 8 to 10 μeq/L) and low base cation concentrations.

Water quality data were collected from May through September, 1970 at about 100 sites in and adjacent to the park by US EPA (1972). Measured pH values ranged from 5.4 to 9.2, with most waters in the range of 7.3 to 7.6. Lowest and highest pH values were attributed to the presence of geothermal waters. Measured average alkalinity values were generally between 20 and 40 mg/L (400 to 800 μeq/L), although a value of 4 mg/L (80 μeq/L) was reported for Duck Lake in early summer. The lowest conductivity measurement found by EPA (1972) was 20 μS/cm, also in Duck Lake, which is located near West Thumb. Hardness as mg/L of $CaCO_3$ was 5.8 mg/L. Such values for specific conductance and hardness would suggest only moderate sensitivity to acidic deposition effects. Duck Lake is a closed basin hydrologically. The calcium concentration in Duck Lake, at 75 μeq/L, was the lowest concentration measured by EPA (1972) in the park.

Gibson et al. (1983) reported the chemistry of 106 lakes in YELL. Data from the major lakes were evaluated; lakes were included from every region of the park and from every major geological formation. The study relied on data already available, rather than conducting a survey as was done for ROMO (Gibson et al. 1983) . A spatial sensitivity map, using alkalinity as an index of vulnerability to acidification, was created for the park based on recent measurements of alkalinity (Figure V-4). Excluding lakes located in the midst of major geothermal areas, the lowest alkalinity measured was 40 μeq/L. Most of the lakes with alkalinity less than 200 μeq/L occurred within the large rhyolite flow which rose from the southwest and spread along the westcentral and central portions of the park (Figure V-1). Six of the 106 lakes evaluated by Gibson et al. (1983) had pH less

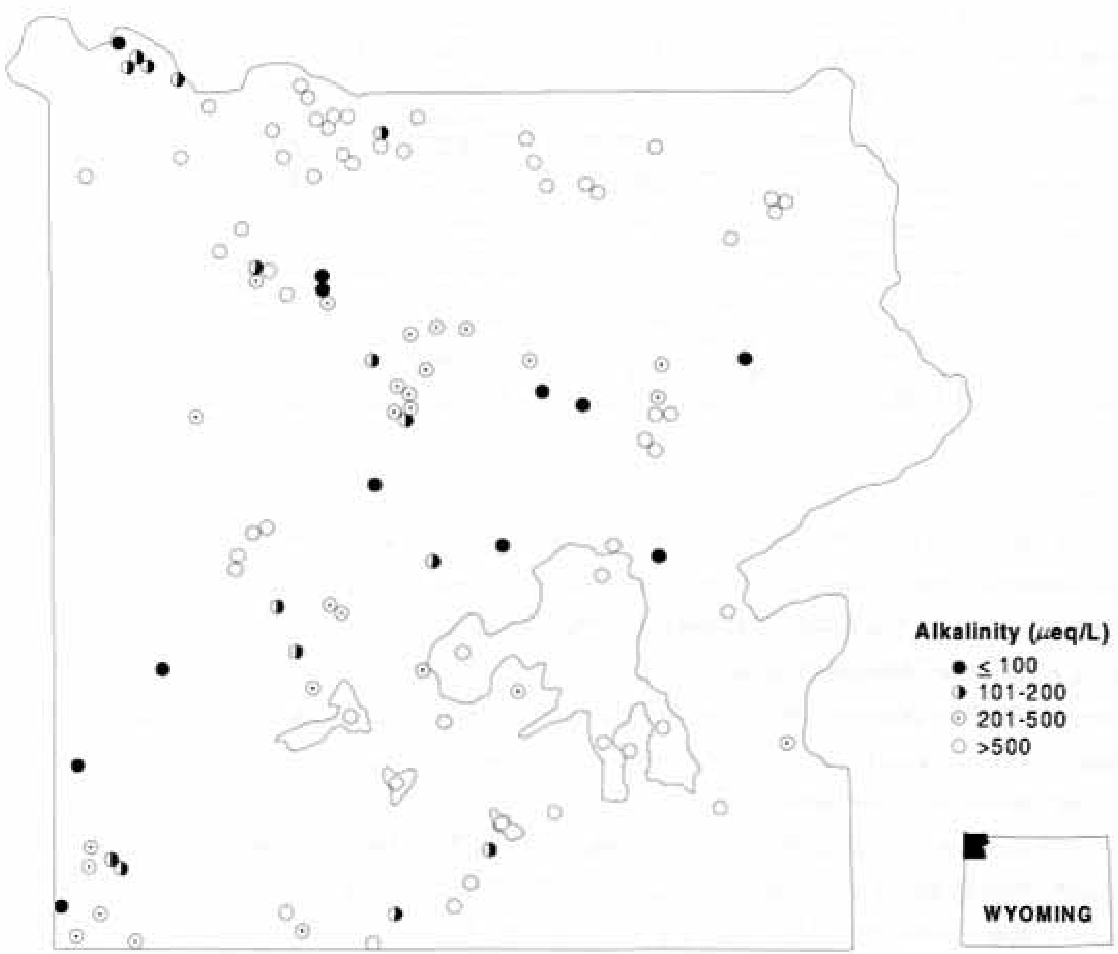


Figure V-4. Alkalinity map for lakes in YELL, prepared from existing data by Gibson et al. (1983).

than 6.5. The authors concluded that two of the six were unquestionably influenced by geothermal contributions and one probably so; the other three were dystrophic. The greatest proportion of high pH and high alkalinity lakes were found in the northern portions of the park. Most of the lakes with alkalinity less than 200 μeq/L were considered naturally barren of fish (Table V-9).

Table V-9. Total alkalinity and fish population status for lakes having ANC < 200 μeq/L in YELL. (Source: Gibson et al. 1983, Varley 1981)

Lake Name	Alkalinity (μeq/L)	Fish Status	
		Historical	Current
Wrangler	40	Fishless	Fishless
Summit	60	Fishless	Fishless
Shelf	80	Fishless	Fishless
Mt. Everts	160	Fishless	Fishless
Ice	200	Fishless	Fishless
Ranger	160	Fishless	(q)
Obsidian	80	Fishless	Brook trout
High	170	Fishless	Cutthroat
Forest	192	Fishless	Cutthroat (q)
Trilobite	200	Fishless	Brook trout
Robinson	100	Cutthroat	Brook trout (q)

(q) Status questionable

Engstrom et al. (1991) cored the sediments of eight small lakes (2-12 ha) in the northern portion of the park to examine the stratigraphic records of past changes in limnology attributable to ungulate grazing. The lakes are located at 1,700 to 2,100 m elevation in the northern winter range area of the park. Although detailed water chemistry was not determined, all eight lakes were reported to have specific conductance greater than 200 μS/cm. Such lakes therefore would have high concentrations of major ions, and would not be expected to be sensitive to potential acidification from acidic deposition.

The stream benthos and periphyton sampled in 1970 (EPA 1972) reflected water of excellent quality throughout the park, with the exception of Soda Butte Creek, which is impacted by leaching from upstream mine tailings outside the park. The flora and fauna of park streams remained relatively unchanged since the first intensive surveys in 1920 and reflected benthic communities typical of unpolluted streams (US EPA 1972).

3. Visibility

As part of the IMPROVE network, visual air quality in YELL has been monitored using an aerosol sampler, transmissometer, and camera. The aerosol sampler has operated from March 1988 through the present and is located at the Lake Village Ranger Station on the northwest shoreline of Yellowstone Lake. The transmissometer operated from July 1989 through July 1993, when monitoring had to be discontinued due to IMPROVE network funding limitations. The transmissometer was located at the southern edge of Mammoth Hot Springs, approximately 6 miles south of the Wyoming-Montana border. The 35mm camera operated from September 1986 through March 1995 and was located on the northern shore of Lake Yellowstone approximately one quarter mile east of the Lake Village Ranger Station. Data from this IMPROVE site have been summarized to characterize the full range of visibility conditions for the March 1988 through February 1995 period, based on seasonal periods (Spring: March, April, and May; Summer: June, July, and August; Autumn: September, October, and November; and Winter: December, January, and February) and annual periods (March through February of the following year, e.g., the annual period of 1994 includes March 1994 through February 1995). Complete descriptions of visibility characterization, mechanisms of sources and visibility impacts, and IMPROVE monitoring techniques and rationale are provided in the Introduction of this report.

a. <u>Aerosol Sampler Data - Particle Monitoring</u>

IMPROVE aerosol samplers consist of four separate particle sampling modules that collect 24-hour filter samples of the particles suspended in the air. The filters are then analyzed in the laboratory to determine the mass concentration and chemical composition of the sampled particles. Particle data can be used to provide a basis for inferring the probable sources of visibility impairment. Practical considerations limit the data collection to two 24-hour samples per week. (Wednesday and Saturday from midnight to midnight). Detailed descriptions of the aerosol sampler, laboratory analysis, and data reduction procedures used can be found in the draft Standard Operating Procedures and Technical Instructions for the IMPROVE Aerosol Sampling Network (U.C. Davis, 1996).

Aerosol sampler data are used to reconstruct the atmospheric extinction coefficient in Mm^{-1} (inverse megameters) from experimentally determined extinction efficiencies of important aerosol species. The extinction coefficient represents the ability of the atmosphere to scatter and absorb light. Higher extinction coefficients signify lower visibility. A tabular and graphic summary of average reconstructed extinction values by season and year for the March 1988 through February 1995 period are provided in Table V-10 and Figure V-5, respectively.

Reconstructed extinction budgets generated from aerosol sampler data apportion the extinction at YELL to specific aerosol species (Figure V-6). The species shown are Rayleigh, sulfate, nitrate,

Table V-10. Seasonal and annual average reconstructed extinction (Mm^{-1}) and standard visual range (km), YELL, March 1988 through February 1995.

YEAR	Spring (Mar, Apr, May)		Summer (Jun, Jul, Aug)		Autumn (Sep, Oct, Nov)		Winter (Dec, Jan, Feb)		Annual (Mar - Feb)[a]	
	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)
1988	30.2	130	53.7	73	30.9	127	24.1	162	34.1	115
1989	30.7	127	42.1	93	33.7	116	24.7	158	33.0	119
1990	32.8	119	41.6	94	31.4	125	26.6	147	33.7	116
1991	29.6	132	39.5	99	31.0	126	26.9	145	32.1	122
1992	31.6	124	40.3	97	32.9	119	24.3	161	32.1	122
1993	27.4	143	29.8	131	33.7	116	21.9	179	28.2	139
1994	30.5	128	42.0	93	30.7	127	21.0	186	31.0	126
Mean[b]	30.4	129	41.3	95	32.0	122	24.2	162	32.0[c]	122[c]

[a] Annual period data represent the mean of all data for each March through February annual period.
[b] Combined season data represent the mean of all seasonal means for each season of the March 1988 through February 1995 period.
[c] Combined annual period data represent the mean of all combined season means.

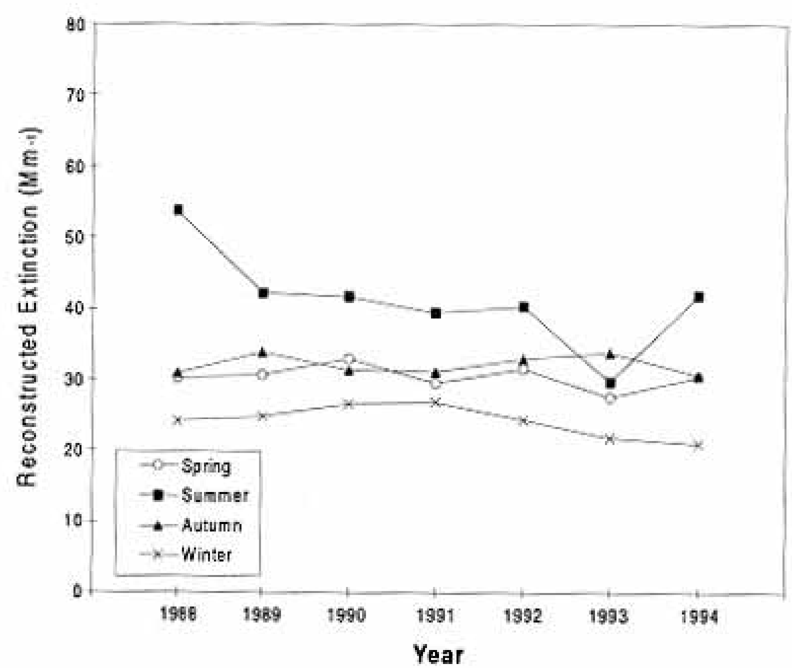


Figure V-5. Seasonal average reconstructed extinction (Mm^{-1}) YELL, March 1988 through February 1995.

Figure V-5. Seasonal average reconstructed extinction (Mm^{-1}) YELL, March 1988 through February 1995.

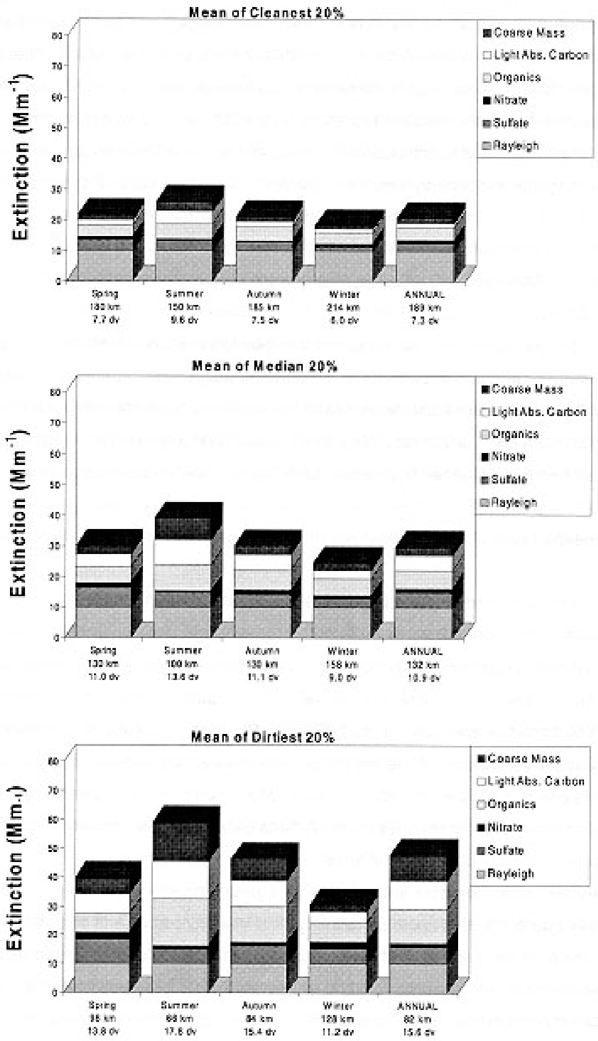


Figure V-6. Reconstructed extinction budgets for YELL, March 1988 - February 1995.

Figure V-6. Reconstructed extinction budgets for YELL, March 1988 - February 1995.

organics, elemental (light absorbing) carbon, and coarse mass. The sum of these species account for the majority of non-weather related extinctions. Extinction budgets are listed by season and by mean of cleanest 20% of days, mean of the median 20% of days, and mean of the dirtiest 20% of days. The "cleanest" and "dirtiest" signify lowest fine mass concentrations and highest fine mass concentrations respectively, with "median" representing the 20% of days with fine mass concentrations in the middle of the distribution. Each budget includes the corresponding extinction coefficient, visual range (in kilometers), and deciview (dv). Standard Visual Range (SVR) can be expressed as:

$$SVR\ (km) = 3{,}912 / (b_{ext} - b_{Ray} + 10)$$

where b_{ext} is the extinction coefficient expressed in inverse megameters (Mm^{-1}), b_{Ray} is the site specific Rayleigh values (elevation dependent), 10 is the Rayleigh coefficient used to normalize visual range, and 3,912 is the constant derived from assuming a 2% contrast detection threshold. The theoretical maximum SVR is 391 km. Note that b_{ext} and SVR are inversely related: for example, as the air becomes cleaner, b_{ext} values decrease and SVR values increase.

Deciview is defined as:

$$dv = 10 \ln(b_{ext}/10Mm^{-1})$$

where b_{ext} is the extinction coefficient expressed in inverse megameters (Mm^{-1}). A one dv change is approximately a 10% change in b_{ext}, which is a small but perceptible scenic change under many circumstances. The deciview scale is near zero (0) for a Rayleigh atmosphere and increases as visibility is degraded. The segment at the bottom of each stacked bar represents Rayleigh scattering, which is assumed to be a constant 10 Mm^{-1} at all sites during all seasons. Rayleigh scattering is the natural scattering of light by atmospheric gases. Higher fractions of extinction due to Rayleigh scattering indicate cleaner conditions.

The reconstructed extinction data are used as background conditions to run plume and regional haze models. These data are also used in the analysis of visibility trends and conditions. The measured extinction data are used to verify the calculated reconstructed extinction and can also be used to run plume and regional haze models and to analyze trends and conditions. Because of the larger spatial and temporal range of the aerosol data, reconstructed extinction data are preferred.

b. Transmissometer Data - Optical Monitoring

The transmissometer system consists of two individually-housed primary components: a transmitter (light source) and a receiver (detector). The light extinction coefficient (b_{ext}) at any time can be calculated based on the intensity of light emitted from the source and the amount of light measured by the receiver (along with the path length between the two). Transmissometers provide continuous, hourly b_{ext} measurements. Meteorological or optical interference factors (such as clouds, rain, or a dirty optical surface) can affect transmissometer measurements. Collected data that may be affected by such interferences are flagged invalid, “filtered”. Seasonal and annual data summaries are typically presented both with and without weather-influenced data. Detailed descriptions of the transmissometer system and data reduction and validation procedures used can be found in Standard Operating Procedures and Technical Instructions for Optec LPV-2 Transmissometer Systems (ARS, 1993 and 1994).

Table V-11 provides a tabular summary of the "filtered" seasonal and combined period arithmetic mean extinction values for the July 1989 through July 1993 period. Table V-12 provides a tabular summary of the "filtered" seasonal and combined period 10% (clean) cumulative frequency values. Data are represented according to the following conditions:

- No data are reported for seasons when the percentage of valid hourly averages (including weather) compared to total possible hourly averages, was less than 50%.

- Annual data represent the mean of all valid seasonal b_{ext} values for each March through February annual period. No data are reported for years that had one or more invalid or missing seasons.

- Combined season data represent the mean of all valid seasonal b_{ext} values for each season (spring, summer, autumn, winter) of the July 1989 through July 1993 period.

- Combined annual period data represent the unweighted mean of all combined seasonal b_{ext} values.

Extinction values in Tables V-11 and V-12 are also presented in units of standard visual range (in kilometers) and deciview (dv).

Figure V-7 provides a graphic representation of the "filtered" annual mean, median, and cumulative frequency values (5th, 10th, 25th, 75th, 90th, and 95th percentiles). No data are reported for annual periods with one or more invalid or missing seasons.

Table V-11. Seasonal and annual arithmetic means for YELL, transmissometer data (filtered) July 1989 thr July 1993.

Year	Spring (Mar, Apr, May)			Summer (Jun, Jul, Aug)			Autumn (Sep, Oct, Nov)			Winter (Dec, Jan, Feb)			Annual (March - Febr	
	SVR	b_{ext} (Mm^{-1})	dv	SVR	b_{ext} (Mm^{-1})	dv	SVR	b_{ext} (Mm^{-1})	dv	SVR	b_{ext} (Mm^{-1})	dv	SVR	b_{ext} (Mm^{-1})
1989				--	--	--	108	35	12.5	154	25	9.2	***	***
1990	138	28	10.3	121	32	11.6	115	33	11.9	133	29	10.6	131	31
1991	117	33	11.9	133	29	10.6	122	31	11.3	154	25	9.2	136	30
1992	133	29	10.6	114	34	12.2	122	31	11.3	161	24	8.8	136	30
1993	125	31	11.3	175	22	7.9							***	***
Mean[b]	128	30	11.1	129	29	10.7	116	33	11.8	150	26	9.5	136	29[c]

-- No data are reported for seasons with <50% valid data.

*** No annual data are reported for periods with one or more invalid seasons.

[a] Annual period data represent the mean of all valid seasonal b_{ext} values for each March through February annual period.

[b] Combined season data represent the mean of all valid seasonal b_{ext} values for each season of tl 1989 through July 1993 period.

[c] Combined annual period data represent the mean of all combined seasonal b_{ext} values.

Table V-12. Seasonal and annual 10% (Clean) cumulative frequency statistics for YELL, transmissometer data (filtered) July 1989 through July 1993.

Year	Spring (Mar, Apr, May)			Summer (Jun, Jul, Aug)			Autumn (Sep, Oct, Nov)			Winter (Dec, Jan, Feb)			Annual (March - February)[a]		
	SVR	b_{ext} (Mm^{-1})	dv	SVR	b_{ext} (Mm^{-1})	dv	SVR	b_{ext} (Mm^{-1})	dv	SVR	b_{ext} (Mm^{-1})	dv	SVR	b_{ext} (Mm^{-1})	dv
1989				--	--	--	169	22	7.9	255	15	4.1	***	***	***
1990	202	19	6.4	183	21	7.4	150	25	9.2	192	20	6.9	190	21	7.5
1991	154	25	9.2	168	23	8.3	162	23	8.3	202	19	6.4	179	23	8.1
1992	183	21	7.4	168	23	8.3	156	24	8.8	239	16	4.7	192	21	7.4
1993	168	23	8.3	192	20	6.9							***	***	***
Mean[b]	175	22	7.9	171	22	7.8	159	24	8.5	219	18	5.6	190	21[3]	7.5

-- No data are reported for seasons with <50% valid data.

*** No annual data are reported for periods with one or more invalid seasons.

[a] Annual period data represent the mean of all valid seasonal b_{ext} values for each March through February annual period.

[b] Combined season data represent the mean of all valid seasonal b_{ext} values for each season of the July 1989 through July 1993 period.

[c] Combined annual period data represent the mean of all combined seasonal b_{ext} values.

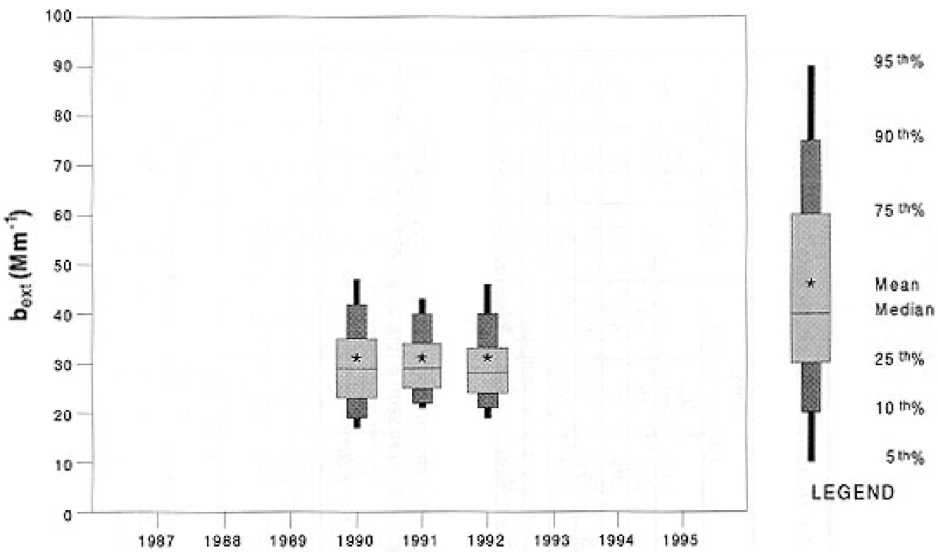


Figure V-7. Annual arithmetic mean and cumulative frequency statistics for YELL, transmissometer data (filtered).

Figure V-7. Annual arithmetic mean and cumulative frequency statistics for YELL, transmissometer data (filtered).

When comparing reconstructed (aerosol) extinction, Table V-10 with measured (transmissometer) extinction, Table V-11 the following differences/similarities should be considered:

Data Collection - Reconstructed extinction measurements represent 24-hour samples collected twice per week. Transmissometer extinction estimates represent continuous measurements summarized as hourly means, 24 hours per day, seven days per week.

Point versus Path Measurements - Reconstructed extinction represents an indirect measure of extinction at one point source. The transmissometer directly measures the irradiance of light (which calculated gives a direct measure of extinction) over a finite atmospheric path.

Note: Differences in daily averages may also be attributed to the 16 mile distance between the Yellowstone aerosol sampler and transmissometer. Optical and aerosol effects often vary with local emissions or meteorological conditions.

Relative Humidity (RH) Cutoff - Daily average reconstructed measurements are flagged as invalid when the daily average RH is greater than 98%. Hourly average transmissometer measurements are flagged invalid when the hourly average RH is greater than 90%. These flagging differences often result in data sets that do not reflect the same period of time, or misinterpret short-term meteorological conditions.

Note: The weather algorithm only flags 10%-20% of the data for a majority of the sites west of the Mississippi River. RH cutoffs have little effect on final mean extinctions in the western United States.

Reconstructed extinction is typically 70%-80% of the measured extinction. With a ratio of 91%, this relationship shows fair agreement for YELL.

c. Camera Data - View Monitoring

An automatic 35mm camera system operated at YELL from September 1986 through March 1995. Color 35mm slide photographs of Overlook Mountain and Lake Yellowstone (to the south) were taken three times per day until the Autumn 1989. The camera alignment changed at that time to photograph Avalanche Peak and Lake Yellowstone (to the southeast) until March 1995.

View monitoring slides document visual conditions and are an effective tool for interpreting the visual effects of measured optical and aerosol parameters or presenting monitoring program goals, objectives, and results to decision-makers and the public. The Avalanche Peak photographs presented in Figure V-8 were chosen to provide a feel for the range of visibility conditions possible and to help relate the extinction/SVR/haziness data to the visual sense.

d. Visibility Summary

Data from other IMPROVE visibility sites around the country have been presented graphically (Figures I-1 and I-2) so that visual air quality in the Rocky Mountains and northern Great Plains can be understood in perspective. Figure V-5 and Table V-11 have been provided to summarize YELL visual air quality during the March 1988 through February 1995, and July 1989 through July 1993 periods respectively. Long-term trends fall into three categories: increases, decreases, and variable. Given the visibility sites summarized for this report, the majority of data show little change or trends.

Non-Rayleigh atmospheric light extinction at YELL, like many rural western areas is largely due to sulfate, organics, and soil. Historically, visibility varies with patterns in weather, winds (and the effects of winds on coarse particles) and smoke from fires. No information is available on how the distribution of visibility conditions at present differs from the profile under "natural" conditions, but the cleanest 20% of the days probably approach natural conditions (GCVTC, 1996). Smoke from frequent fires is suspected to have reduced pre-settlement visibility below current levels during some summer months.

The IMPROVE aerosol monitoring network, established in March 1988, consists of sites instrumented with aerosol sampling modules A through D. Many of the IMPROVE sites are successors to sites where aerosol monitoring with stacked filter units (SFU) was carried out as early

Yellowstone National Park
on a "clear" day

Representative Conditions:
Visual Range: 260-300 km
b_{ext}: 15-13 Mm^{-1}
Haziness: 4-3 dv

Yellowstone National Park
on an "average" day

Representative Conditions:
Visual Range: 130-170 km
b_{ext}: 30-23 Mm^{-1}
Haziness: 11-8 dv

Yellowstone National Park
on a "dirty" day

Representative Conditions:
Visual Range: 75-95 km
b_{ext}: 52-41 Mm^{-1}
Haziness: 17-14 dv

Figure V-8. Photographs illustrating visibility conditions at Yellowstone National Park.

Figure V-8. Photographs illustrating visibility conditions at Yellowstone National Park.

as 1979. SFU data were collected at YELL from October 1979 through December 1987. No long-term trends are apparent in the 1979 through 1987 SFU data or the 1988 through 1994 site-specific or regional data presented in this report.

D. AIR QUALITY RELATED VALUES

1. Aquatic Biota

Sensitive fish species in the park include both native and non-native salmonids. Recent studies have shown that native western trout are sensitive to short-term increases in acidity. For example, Woodward et al. (1989) exposed native western cutthroat trout (*Oncorhynchus clarki*) to pH depressions (pH 4.5 to 6.5) in the laboratory. Freshly-fertilized egg, eyed embryo, alevin, and swim-up larval stages of development were exposed to low pH for a period of seven days. Fish life stages were monitored for mortality, growth, and development to 40 days posthatch. The test fish were taken from the Snake River in Wyoming. Reductions in pH from 6.5 to 6.0 in low-calcium water (70 μeq/L) did not affect survival, but did reduce growth of swim-up larvae. Eggs, alevins, and swim-up larvae showed significantly higher mortality at pH 4.5 as compared to pH 6.5. Mortality was also somewhat higher at pH 5.0, but only statistically higher for eggs. Survival of various life stages of Yellowstone cutthroat trout exposed to 7-day pH depressions in order to simulate episodic acidification was studied by Farag et al. (1993). They also evaluated the added toxicity associated with elevated concentrations of Al. However, we note procedural problems associated with their Al exposures (i.e., Al added in excess of the amount soluble at a given pH) and therefore only consider data for evaluating fish response to pH depressions. Of the four life stages studied in Yellowstone cutthroat trout, eggs were most sensitive to low pH. Eggs exposed to pH 5.0 experienced a statistically-significant reduction in survival when compared with eggs exposed for seven days to pH 6.5 water. Survival of alevin and swim-up larvae was reduced from near 100% at pH 6.5 to near zero percent at pH 4.5. Intermediate pH values (6.0, 5.5) in all cases showed reduced survival compared with the control (6.5) but not by a statistically significant amount. Eyed embryos were not sensitive to any of the exposures.

2. Terrestrial

Vegetation is the resource which is most sensitive to ozone and SO_2, and several tree species have been identified as potential bioindicators (see below). Additional studies would be needed to evaluate the impact of SO_2 and ozone on terrestrial ecosystems in YELL. While ozone and SO_2 levels have not exceeded the NAAQS in YELL, future levels could potentially damage sensitive plant species. Furthermore, baseline data on the condition of sensitive species in the absence of injurious pollutants would be helpful for comparison if pollutant levels increase. Monitoring sensitive receptors (those species with known sensitivity to one or more pollutants) by using detailed descriptions and classifications of sensitive indicators (characteristics of leaf or plant injury) will be necessary for long-term evaluation of ecosystem health.

One of the most ozone-sensitive Western tree species is ponderosa pine (*Pinus ponderosa*, especially var. *ponderosa*), for which extensive data are available on field (Miller and Millecan 1971, Pronos and Vogler 1981, Peterson and Arbaugh 1988) and experimental (Temple et al. 1992) exposures. The evidence for ozone impacts on ponderosa pine is based on observable symptoms and reduced growth (Peterson et al. 1991, Peterson and Arbaugh 1992) as well as physiological (Darrall 1989, Bytnerowicz and Grulke 1992) data. The cause-and-effect relationship, especially for trees growing in forests of southern California and the southern Sierra Nevada, is clear and quantifiable.

Lodgepole pine is more tolerant to ozone and does not exhibit symptoms of injury under low experimental exposures that would result in symptoms to ponderosa pine (Aitken et al. 1984). Nevertheless, the well-documented and quantifiable symptomatology of pines makes lodgepole pine an acceptable bioindicator for ozone, even if it has only moderate sensitivity. Lodgepole pine is very widespread in YELL, and several areas in the park are suitable for establishing long-term monitoring plots.

Of the hardwood species present in YELL, quaking aspen is the most sensitive to ozone and may be the most ozone-sensitive tree species in the park. Aspen grows at various locations in riparian ecosystems and in fire- or avalanche-disturbed areas in the park. Numerous studies have documented the sensitivity of this species to ozone under field and experimental conditions (Wang et al. 1986, Karnosky et al. 1992, Coleman et al. 1996), although there is considerable variability in sensitivity among different genotypes (Berrang et al. 1986). Diagnostic ozone symptomatology for aspen includes chlorosis, stippling, necrotic spotting, and leaf margin burn. Symptoms generally vary seasonally, with stippling being most prominent in the spring and black, bifacial (both leaf surfaces) necrosis appearing in late summer (J.P. Bennett, pers. comm.). Great care must be taken in distinguishing ozone symptoms from the effects of various pathogens and insect herbivores commonly found on this species.

Aspen is also considered to be sensitive to SO_2 and may be the best sensitive receptor for this gaseous pollutant. Injury is similar to that normally found for ozone (stippling, followed by bifacial necrosis), although SO_2 -induced injury rapidly bleaches to a light tan color (ozone injury remains dark) (Karnosky 1976). There could be some confusion in differentiating ozone injury from SO_2 injury.

Black cottonwood is another potential sensitive receptor for ozone (Woo 1996), and it has symptoms similar to those of aspen. However, it is generally regarded as less sensitive to ozone than aspen. Neither of these hardwood species has the clarity of ozone symptomatology found in lodgepole pine.

A species list of native plants is available in the NPFlora database. Table V-13 summarizes vascular plant species of YELL with known sensitivity to ozone, SO_2 and NO_x. This table is based on a variety of sources from the published literature and other information. It should be noted that the various sources used a wide range of field and experimental approaches to determine pollutant pathology, and that sensitivity ratings are general estimates based on published information and our expert opinion. While it will not be possible for park staff to collect data on all the species indicated in Table V-13, the list can be used by park managers as a guide for identifying visible symptoms. Of the many plant species in YELL, it is likely that there are many other species which have high sensitivity to air pollution, but we currently have no information about them.

Table V-13. Plant species of YELL with known sensitivities to sulfur dioxide, ozone and nitrogen oxides. (H=high, M=medium, L=low, blank=unknown). (Sources: Esserlieu and Olson 1986, Bunin 1990, Peterson et al. 1993, Electric Power Research Institute 1995, Binkley et al. 1996, Brace and Peterson 1996)

Species Name	SO_2 Sensitivity	O_3 Sensitivity	NO_x Sensitivity
Abies lasiocarpa	L	L	
Acer glabrum	H		
Alnus tenufolia	H		
Betula occidentalis	M		
Bromus carinatus		L	
Bromus tectorum		M	
Ceanothus velutinus	L		
Chenopodium fremontii		L	
Cirsium arvense		L	
Cirsium undulatum	M		
Clematis ligusticifolia	M		
Collomia linearis		L	
Convolvulus arvensis	H		
Cornus stolonifera	M	L	
Descurainia pinnata		L	
Epilobium angustifolium		L	
Erigeron peregrinus		L	
Fragaria virginiana		H	
Galium bifolium		L	
Gaultheria shallon		L	
Gayophytum racemosum		L	
Gentiana amarella		M	
Geranium richardsonii	M	M	
Hackelia floribunda	L		
Hedysarum boreale		M	
Helianthus anuus	H	L	

Table V-13. Continued.

Species Name	SO_2 Sensitivity	O_3 Sensitivity	NO_x Sensitivity
Juniperus communis	L		
Juniperus scopulorum	L		
Lemna minor	L		
Lolium perenne		M	
Lonicera involucrata	L	H	
Medicago sativa		M	
Mentzelia albicaulis		H	
Mimulus guttatus		L	
Oryzopsis hymenoides	M		
Phyllodoce empetriformis		L	
Picea engelmannii	M	L	
Picea glauca	M	L	
Pinus contorta	M	M	H
Pinus flexilis	L		
Poa annua	H	L	
Poa pratensis		L	
Polygonum douglasii		L	
Populus angustifolia	M		
Populus balsamifera subsp. *trichocarpa*	M	H	
Populus tremuloides	H	H	
Potentilla fruticosa		L	
Prunus virginiana	M	H	
Pseudotsuga menziesii	M	L	H
Rhus trilobata	L	H	
Ribes viscosissimum	M		
Rosa woodsii	M	L	
Rubus idaeus	H		
Rubus parviflorus		M	
Rumex crispus		L	
Salix scouleriana		M	
Senecio serra		H	
Shepherdia canadensis	L		
Sorbus scopulina	M		
Symphoricarpos oreophilus	M		
Taraxacum officinale		L	
Toxicodendron radicans	L	L	
Tragopogon dubius	M		
Trifolium pratense	L		
Trifolium repens		H	
Trisetum spicatum	M		

Vicia americana		L	
Viola adunca		L	

An inventory of lichen species with known sensitivity to ozone and SO_2 is summarized in Table V-14. As in Table V-13, this table is based on a variety of sources from the published literature and other information. It should be noted that diagnostic symptoms of air pollutant injury to lichens are difficult to identify, and that some species have reduced productivity or even mortality without exhibiting visible symptoms (Nash and Wirth 1988). One of the best sources of background information and guidelines for addressing the use of lichens as sensitive receptors of air pollution is Stolte et al. (1993). The inventory of lichen species performed by Eversman (1990) provides a good baseline for further assessment of potential impacts of air pollution.

Table V-14. Lichen species of YELL with known sensitivity to SO_2 and ozone. (H=high, M=medium, L=low, blank=unknown). (Sources: Peterson et al. 1993, National Park Service 1994, Electric Power Research Institute 1995, Binkley et al. 1996)

Species	SO_2 sensitivity	Ozone sensitivity
Acarospora chlorophana	H	
Aspicilia caesiocinerea	L	
Bryoria abbreviata		H
Bryoria fremontii		H
Bryoria fuscescens	M	
Candelaria concolor	M-H	
Candelariella vitellina	M	
Candelariella xanthostigma	M	
Cladonia chlorophaea	M	
Cladonia coniocraea	M	
Cladonia fimbriata	M-H	
Coeocaulon muricatum	L-M	
Collema nigrescens		M
Evernia mesomorpha	M	
Hypogymnia imshaugii	L-M?	L-M
Hypogymnia physodes	M	
Lecanora saligna	M	
Lecidea atrobrunnea	L	
Lepraria incana	L-M	
Letharia columbiana	L	L-M
Letharia vulpina	L	L-M

Melanelia exasperatula	M	
Melanelia subolivacea		L-M
Parmelia saxatilis	M	L
Parmeliopsis hyperopta	M	
Peltigera aphthosa	M	H

Table V-14. Continued.

Species	SO_2 sensitivity	Ozone sensitivity
Peltigera canina	L	H
Peltigera collina		H
Peltigera polydactyla	M	
Peltigera refuscens		M-H
Phaeophyscia orbicularis	M	H
Phaeophyscia sciastra		H
Physcia adscendens	M	
Physcia aipolia	M	
Physcia caesia	M	
Physcia dubia	M	
Physcia stellaris	M	
Physconia detersa	M-H	L
Pseudephebe pubescens		M
Rhizoplaca chrysoleuca	H	
Rhizoplaca melanophthalma	H	
Usnea hirta	M-H	
Xanthoparmelia cumberlandia	H	
Xanthoria candelaria	M-H	H
Xanthoria elegans	M	
Xanthoria fallax	M-H	L
Xanthoria polycarpa	M-H	L

E. RESEARCH AND MONITORING NEEDS

1. Deposition and Gases

Deposition of sulfur and nitrogen is monitored at Tower Junction. This site provides sufficient data for YELL, given that the aquatic resources within the park are generally insensitive to adverse effects of acidic deposition and that current deposition levels at Tower Junction are very low.

Ozone pollution in YELL is currently at a level below that which would be expected to adversely affect sensitive plant species. The continuous ozone analyzer at Lake should continue to be operated in order to document any future changes. In addition, it would be useful to establish a network of passive ozone samplers to compare ozone measurements from different locations in the park. Five samplers should be sufficient to spatially characterize the ozone distribution: (1)

colocated with the continuous ozone analyzer at Lake, (2) west of Mammoth Hot Springs, (3) near the northeast entrance, (4) near the Bechler Ranger Station, and (5) southeast portion of the park on the Yellowstone River. It would also be desirable to determine differences in ozone exposure across an elevation gradient within the park. Samplers should be situated where they are reasonably accessible but not within 50 m of a road or trail where they may be subject to excessive dust or vandalism. Weekly samples collected for two months during each summer for a period of three years should be sufficient to establish spatial patterns and a reference point in time.

Because of the current concern regarding CO and its potential impacts on human health, we recommend that YELL continue to monitor CO emissions in the park. Emphasis should be placed on high-traffic areas within the park, especially areas where park personnel and others are exposed to the gas for long periods of time. Monitoring will be particularly important during peak summer (passenger vehicle) and winter (snowmachine) traffic. We also recommend that the park consult with a human respiratory (or other appropriate) specialist to determine if current levels of CO exposure are sufficient to cause physiological impairment in park personnel and visitors.

2. Aquatic Systems

We do not recommend any additional monitoring or research on the sensitivity of aquatic ecosystems within YELL to air pollution degradation. There are several reasons for this. First, lakes and streams in the park are, for the most part, not sensitive to acidification impacts. We base this on examination of available water chemistry data from the park (e.g., Tables V-7, V-8, and V-9), including data from the Western Lakes Survey, STORET, and the National Park Service database for YELL. Base cation concentrations and ANC tend to be higher than commonly-accepted thresholds of sensitivity. Second, many of the surface waters in the park receive substantial contributions of mineral acid anions from geothermal sources; this would obfuscate future efforts to assess cause/effect relationships associated with air pollution impacts. Third, YELL is exposed to the same general airshed as GRTE which contains aquatic resources of greater sensitivity. Monitoring for air pollution effects on aquatic resources would be better conducted in GRTE.

3. Terrestrial Systems

Monitoring of terrestrial resources should be considered in order to establish a baseline of current conditions with respect to the potential impacts of ozone and SO_2. Three levels of monitoring associated with increasing amounts of effort and expense are detailed in Appendix A. These monitoring activities are based on methods and protocols developed by the USDA Forest Service and NPS. Species and locations recommended for monitoring are listed below.

If monitoring is implemented, we recommend placing plots at three locations in the vicinity of the Tower Lake monitoring station. These plots should be located away from human-use areas and preferably in areas with good air flow. Species recommended for monitoring are lodgepole pine and quaking aspen. If necessary, additional plots could be located near the south entrance. These areas are all located along river drainages where maximum air flow can be expected. Locations of these plots can be changed to other sites in YELL if ambient air quality data indicate that other areas have a higher risk of pollutant effects.

Additional tree plots that evaluate other conifer species, such as Engelmann spruce, and Douglas-fir could be located along elevational transects. These additional plots should be located adjacent to the location of plots discussed above. If herbaceous plants are included in the monitoring effort, candidate species that are known to exist in YELL include strawberry (*Fragaria virginiana),* skunkbush (*Rhus trilobata*), and red clover (*Trifolium repens*). A large-scale monitoring effort for lichens is not justified at this point, although protocols and guidelines in Stolte et al. (1993) can be consulted for information on assessing injury.

4. Visibility

IMPROVE aerosol monitoring continues today at YELL. Continued monitoring is necessary to identify potential future impacts. Additional data and in-depth modeling and analysis are required to further evaluate historical trends and future projections of impact from existing and future sources. For example, back trajectory analysis and spatial/temporal pattern analysis of episodes are recommended to determine the source region contributions to elevated aerosol concentrations. Future research is also recommended to minimize the uncertainty in estimates of how various aerosol species affect visibility.